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学位論文題目（英文）	Mineralogical and Geochemical Characteristics of the Utanobori and Omui Epithermal Gold Deposits and the Omu Silica Sinter in Northeastern Hokkaido, Japan (日本，北海道北東部，歌登および雄武威浅熱水金鉱床，雄武シリカシンターの鉱物学的–地球化学的特徴)
論 文 審 査 委 員	（主査）教授　大場　司 （副査）教授　渡辺　寧 （副査）教授　Antonio Arribas （副査）教授　Andrea Agangi （副査）教授　今井　亮

論文内容の要旨

The Northeast Hokkaido Metallogenic Province in the northeastern part of Hokkaido in Japan is host to epithermal precious and base metal deposits, volcanic massive sulfide (Kuroko) deposits, and subaerial-volcanic exhalative hydrothermal deposits. Amongst the various deposits, the Utanobori and Omui low sulfidation epithermal vein-type deposits, and the Omu silica sinter were studied. The objective of the study is to understand the characteristics of the silica sinter and ore-bearing veins and their relationship to mineralization and associated volcanic events on the basis of field relations, petrography, Ar-Ar and K-Ar age dating, X-ray diffractometry (XRD), inductively coupled plasma mass spectrometry (ICP-MS), atomic absorption spectroscopy (AAS), energy-dispersive X-ray spectroscopy-scanning electron microscopy (SEM-EDX), cathodoluminescence (CL), electron probe micro analysis (EPMA), and sulfur isotope analyses.

Mineralized veins of the Utanobori deposit are hosted by the Middle to Late Miocene Esashi Formation, which consists of conglomerate, sandstone, and tuff. Silica sinter and quartz-adularia veins are exposed in the Utanobori deposit. The quartz-adularia veins with ginguro bands are divided into three stages with twelve to fourteen sub-stages. Ore minerals identified include electrum, naumannite, chlorargyrite, bromargyrite and trace pyrite. These ore minerals were formed in the main

mineralization stages I (bands I-b and I-d) and II (band II-a). An unidentified Fe-Sb secondary mineral is also present in the veins. Alteration assemblages imply near-neutral pH conditions during ore deposition. The SEM-CL images show that CL-dark microcrystalline quartz exhibiting colloform (ghost-sphere) texture is closely associated with ore minerals. Concentrations of Al, Fe, K, Ti, and Mn of quartz of the quartz-adularia vein with ginguro band and silica sinter were determined using EPMA. In the quartz-adularia vein with ginguro band, Al and K contents of CL-dark microcrystalline quartz exhibiting colloform (ghost-sphere) texture are commonly >1000 ppm. This may imply that ore minerals were crystallized from alkaline and silica supersaturated fluids at temperatures <200ºC which deposited initially amorphous silica with primary colloform texture that were crystallized to microcrystalline quartz. The δ34SCDT values of fine-grained disseminated pyrite in the altered conglomerate and bedded tuff in the argillic altered zone are -4.3 ‰ and -4.2 ‰. Mineralization ages of the quartz-adularia vein with ginguro of the stages I, II and III by Ar-Ar dating determined on adularia are 13.6±0.06 Ma, 13.6±0.07 Ma, and 13.6±0.06 Ma, respectively. From available radiometric age data and field observations, two separate events of rhyolite volcanism were recognized. The first closely associated with the deposition of early formed silica sinter, and the second closely associated with the later formed mineralized quartz-adularia veins.

Mineralized veins of the Omui epithermal gold deposit are hosted by rhyolite lapilli tuff of the Miocene Propylite Lava. Approximately 8 km north of the Omui deposit, outcrops of silica sinter (Omu sinter) forming up to 3.2 m high terraces are observed south of the Otoineppu river. The mineralized quartz veins of the Omui deposit (Hopi vein) show early, middle and late stages of mineralization. The middle stage represents the main mineralization event. Abundant quartz and thin (<1 mm) ginguro bands were formed in the early stage. Mineralization accompanied with brecciation deposited ore during the middle stage, followed by the precipitation of abundant quartz and trace ginguro bands in the late stage. Kaolinite observed in the quartz veins was formed in the early and middle stages, and is lesser in the late stage. Adularia and illite were also formed, but in minor to trace amounts in the veins. Bladed calcite was formed at places in the early and middle stages. Electrum, argentite and stephanite formed in the middle stage, closely associated with microcrystalline quartz.

The Omu silica sinter is massive, and brecciated at intervals. The silica sinter is 3.2 m high and dips gently NW. Twenty nine (29) layers were recognized. Structures of the silica sinter observed includes thick (massive) and finely laminated, sinter clast breccia, low-amplitude wavy stromatolite, network and streamer fabrics, geyserite eggs, and plant-rich sinter. The Au content of the sulfide-rich brecciated base of the silica sinter is >1 ppm, and >0.1 ppm in the upper sinter clast breccia layers. The Au and Ag contents of the silica sinter are positively correlated. Base on studies conducted on thermophilic

microbes that thrive along gradients of pH, geothermal fluid flow rate, fluid composition and temperature of the silica sinter lithofacies, geyserite eggs suggest temperatures of deposition range from >75ºC, and from ~60 to 75ºC for the thinly laminated, and from ~25 to ~40ºC for the thickly laminated and plant-rich sinter layers. K-Ar dating conducted on hornblende of a Rhyolite Dike reveals an age of 14.3 Ma, suggesting that the Rhyolite Dike pre-dates the Motoineppu Lava that hosted the quartz veins at the Omui deposit. The relationship of the Rhyolite Dike to mineralization is uncertain, but it may had played a role as a heat source for hydrothermal activities. The ore-forming age is not reported yet. The association of electrum with microcrystalline quartz in Omui is similar to that of the Utanobori deposit.

The deposition of silica sinters and the hydrothermal mineralization in the Utanobori and Omui epithermal gold deposits were closely related to rhyolite volcanism in each area. Quartz textures and structures were observed in mineralized veins of the Utanobori and Omui gold deposits suggest that gold was precipitated with initially amorphous silica that crystallized to microcrystalline and mosaic quartz. Silica sinters in both deposits were overprinted, suggesting that repeated hydrothermal events occurred after silica sinters were deposited. In comparison to other low sulfidation epithermal vein-type deposits, this study has shown two of few examples where silica sinter is mineralized by cross-cutting ore-bearing veins.

論文審査結果の要旨

提出された博士論文，博士論文要旨及び論文目録について，所属する資源学専攻の教員および外部審査委員により構成される審査委員会において審査し，不備がないことを確認した。記載内容は適正であり，また，査読のある学術誌に投稿された論文が受理されていることを確認し，書類審査は合格とした。申請者は，北海道北東部の歌登および雄武威浅熱水金鉱床および雄武シリカシンターとそれらを伴った火山活動について，詳細に検討した。

まず著者は， 歌登鉱床周辺の地質について概説した後，銀黒縞を伴う石英–氷長石の鉱脈鉱化作用は大きく 3 つのステージ，細かくは 12 ないし 14 のサブステージに分けられることを明らかにした。認められた鉱石鉱物はエレクトラム，ナウマン鉱，角銀鉱，臭化銀鉱および微量の黄鉄鉱である。これらの鉱石鉱物は，主要な鉱化ステージ I（サブステージ I-b 及び I-d）およびステージ II（サブステージ II-a）に生成した。走査電子顕微鏡を用いたカソードルミネッセンス像（SEM-CL 像）によると，鉱石鉱物はコロフォーム組織を示す暗 CL 石英に伴われる。コロフォーム組織を呈する暗 CL 石英の Al および K 含有量は>1000ppm である。これらは 200℃以下のアルカリ性のシリカに過飽和な熱水から初生的にコロフォーム組

織を呈する非晶質シリカとして沈殿し，微細石英に結晶化したと考えられる。粘土化変質した母岩中に鉱染した黄鉄鉱の硫黄同位体比の $\delta^{34}S_{CDT}$ 値は-4.3‰及び-4.2‰であった。銀黒縞を伴う石英–氷長石脈のステージ I, II, III の氷長石の Ar-Ar 年代はそれぞれ 13.6±0.06Ma, 13.6±0.07Ma，13.6±0.06Ma であった。２つの時間的に異なる流紋岩質マグマ活動があり，最初の活動に伴われてシリカシンターが生成し，次の活動により鉱化作用を伴なう石英–氷長石が生成した。

次に著者は，雄武威浅熱水金鉱床について記載している。雄武威鉱床の鉱化した鉱脈も前期，中期，後期の３つのステージに分けられ，主たる鉱化作用は中期に生じ，エレクトラム，輝銀鉱，脆銀鉱が微晶石英に伴われている。早期および中期には葉片状方解石が生じた。

続いて著者は，雄武威鉱床の北約 8km に露出している雄武シリカシンカーについて記載している。シンターは厚さ 3.2m で，29 の層に区分できる。シンターの金含有量と銀含有量は相関する。シンターの沈殿温度は，球状シリカが>75℃，薄層部は 60-75℃，植物片に富む厚層部は 25-45℃と推定された。鉱床周辺に存在する流紋岩岩脈の普通角閃石の K-Ar 年代は 14.3Ma である。

最後に著者は，歌登鉱床および雄武威鉱床において，熱水活動が流紋岩質火山活動に伴われたこと，石英の組織および構造から，金は初生的に非晶質なシリカの沈殿に伴われて晶出し，非晶質シリカが微晶石英に結晶化したこと，双方の鉱床において，先に生成していたシリカシンターにオーバープリントを生じた熱水活動により鉱脈が生成したことをまとめた。

本学位論文は，これまで研究例がなく鉱床の詳細についてほとんど知られていなかった歌登鉱床よび雄武威鉱床における鉱化作用，および雄武シリカシンターについて，鉱化作用の特徴，熱水の化学的特徴，生成環境，生成史を明らかにした。博士の学位に値する業績であると認め，本審査は合格と判定した。